# Boron carbide

**Boron carbide** (chemical formula approximately $B_4C$) is an extremely hard boron–carbon ceramic and covalent material used in tank armor, bulletproof vests, engine sabotage powders,[1] as well as numerous industrial applications. With a Vickers hardness of >30 GPa, it is one of the hardest known materials, behind cubic boron nitride and diamond.[2]

**Boron carbide**

**Names**

IUPAC name
Boron carbide

Other names
Tetrabor

**Identifiers**

| | |
|---|---|
| CAS Number | 12069-32-8 (https://commonchemistry.cas.org/detail?cas_rn=12069-32-8) ✓ |
| 3D model (JSmol) | Interactive image (https://chemapps.stolaf.edu/jmol/jmol.php?model=B12B3B4B1C234) |
| ChemSpider | 109889 (https://www.chemspider.com/Chemical-Structure.109889.html) ✓ |
| ECHA InfoCard | 100.031.907 (https://echa.europa.eu/substance-information/-/substanceinfo/100.031.907) |
| PubChem CID | 123279 (https://pubchem.ncbi.nlm.nih.gov/compound/123279) |
| UNII | T5V24LJ508 (https://fdasis.nlm.nih.gov/srs/srsdirect.jsp?regno=T5V24LJ508) ✓ |
| CompTox Dashboard (EPA) | DTXSID4051615 (https://comptox.epa.gov/dashboard/chemical/details/DTXSID4051615) |

InChI

InChI=1S/CB4/c2-1-3(2)5(1)4(1)2 ✓
Key: INAHAJYZKVIDIZ-UHFFFAOYSA-N ✓

InChI=1/CB4/c2-1-3(2)5(1)4(1)2
Key: INAHAJYZKVIDIZ-UHFFFAOYAS

| | |
|---|---|
| SMILES<br>B12B3B4B1C234 | |
| **Properties** | |
| Chemical formula | $B_4C$ |
| Molar mass | 55.255 g/mol |
| Appearance | dark gray or black powder, odorless |
| Density | 2.52 g/cm$^3$, solid. |
| Melting point | 2,763 °C (5,005 °F; 3,036 K) |
| Boiling point | 3,500 °C (6,330 °F; 3,770 K) |
| Solubility in water | insoluble |
| **Structure** | |
| Crystal structure | Rhombohedral |
| **Hazards** | |
| Safety data sheet (SDS) | External MSDS (http://www.logitech.uk.com/MSDS/Files%5C0CON-024%20to%20028.pdf) |
| **Related compounds** | |
| Related compounds | Boron nitride |
| Except where otherwise noted, data are given for materials in their standard state (at 25 °C [77 °F], 100 kPa).<br>✓ verify (https://en.wikipedia.org/w/index.php?title=Special:ComparePages&rev1=430790006&page2=Boron+carbide) (what is ✓✗ ?)<br>Infobox references | |

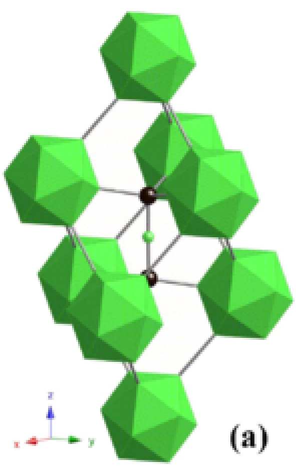
## History

Boron carbide was discovered in the 19th century as a by-product of reactions involving metal borides, but its chemical formula was unknown. It was not until the 1930s that the chemical composition was estimated as $B_4C$.[3] Controversy remained as to whether or not the material

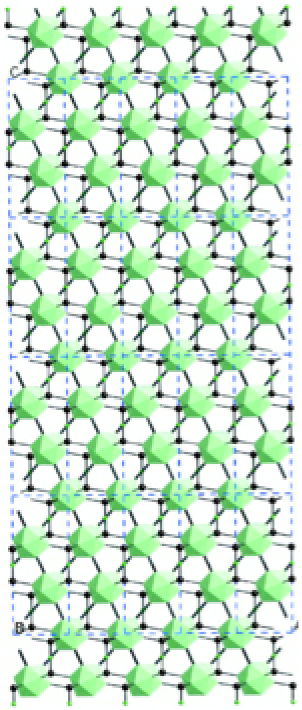
had this exact 4:1 stoichiometry, as, in practice the material is always slightly carbon-deficient with regard to this formula, and X-ray crystallography shows that its structure is highly complex, with a mixture of C-B-C chains and $B_{12}$ icosahedra.

These features argued against a very simple exact $B_4C$ empirical formula.[4] Because of the $B_{12}$ structural unit, the chemical formula of "ideal" boron carbide is often written not as $B_4C$, but as $B_{12}C_3$, and the carbon deficiency of boron carbide described in terms of a combination of the $B_{12}C_3$ and $B_{12}CBC$ units.

## Crystal structure




*Unit cell of $B_4C$. The green sphere and icosahedra consist of boron atoms, and black spheres are carbon atoms.*[5]




*Fragment of the $B_4C$ crystal structure.*

Boron carbide has a complex crystal structure typical of icosahedron-based borides. There, $B_{12}$ icosahedra form a rhombohedral lattice unit (space group: $R\overline{3}m$ (No. 166), lattice constants: $a$ = 0.56 nm and $c$ = 1.212 nm) surrounding a C-B-C chain that resides at the center of the unit cell, and both carbon atoms bridge the neighboring three icosahedra. This structure is layered: the $B_{12}$ icosahedra and bridging carbons form a network plane that spreads parallel to the *c*-plane and stacks along the *c*-axis. The lattice has two basic structure units – the $B_{12}$ icosahedron and the $B_6$ octahedron. Because of the small size of the $B_6$ octahedra, they cannot interconnect. Instead, they bond to the $B_{12}$ icosahedra in the neighboring layer, and this decreases bonding strength in the *c*-plane.[5]

Because of the $B_{12}$ structural unit, the chemical formula of "ideal" boron carbide is often written not as $B_4C$, but as $B_{12}C_3$, and the carbon deficiency of boron carbide described in terms of a combination of the $B_{12}C_3$ and $B_{12}C_2$ units.[4][6] Some studies indicate the possibility of incorporation of one or more carbon atoms into the boron icosahedra, giving rise to formulas such as $(B_{11}C)CBC = B_4C$ at the carbon-heavy end of the stoichiometry, but formulas such as $B_{12}(CBB) = B_{14}C$ at the boron-rich end. "Boron carbide" is thus not a single compound, but a family of compounds of different compositions. A common intermediate, which approximates a commonly found ratio of elements, is $B_{12}(CBC) = B_{6.5}C$.[7] Quantum mechanical calculations

have demonstrated that configurational disorder between boron and carbon atoms on the different positions in the crystal determines several of the materials properties - in particular, the crystal symmetry of the $B_4C$ composition[8] and the non-metallic electrical character of the $B_{13}C_2$ composition.[9]

# Properties

Boron carbide is known as a robust material having extremely high hardness (about 9.5 up to 9.75 on Mohs hardness scale), high cross section for absorption of neutrons (i.e. good shielding properties against neutrons), stability to ionizing radiation and most chemicals.[10] Its Vickers hardness (38 GPa), Elastic Modulus (460 GPa)[11] and fracture toughness (3.5 MPa·m$^{1/2}$) approach the corresponding values for diamond (1150 GPa and 5.3 MPa·m$^{1/2}$).[12]

As of 2015, boron carbide is the third hardest substance known, after diamond and cubic boron nitride, earning it the nickname "black diamond".[13][14]

## Semiconductor properties

Boron carbide is a semiconductor, with electronic properties dominated by hopping-type transport.[7] The energy band gap depends on composition as well as the degree of order. The band gap is estimated at 2.09 eV, with multiple mid-bandgap states which complicate the photoluminescence spectrum.[7] The material is typically p-type.

# Preparation

Boron carbide was first synthesized by Henri Moissan in 1899,[6] by reduction of boron trioxide either with carbon or magnesium in presence of carbon in an electric arc furnace. In the case of carbon, the reaction occurs at temperatures above the melting point of $B_4C$ and is accompanied by liberation of large amount of carbon monoxide:[15]

$$2\ B_2O_3 + 7\ C \rightarrow B_4C + 6\ CO$$

If magnesium is used, the reaction can be carried out in a graphite crucible, and the magnesium byproducts are removed by treatment with acid.[16]

# Applications

*Boron carbide is used for inner plates of ballistic vests*

For its hardness :

- Padlocks
- Personal and vehicle anti-ballistic armor plating
- Grit blasting nozzles
- High-pressure water jet cutter nozzles
- Scratch and wear resistant coatings
- Cutting tools and dies
- Abrasives
- Metal matrix composites
- In brake linings of vehicles

For other properties :

- Neutron absorber in nuclear reactors (see below)
- High energy fuel for solid fuel ramjets

## Nuclear Applications

The ability of boron carbide to absorb neutrons without forming long-lived radionuclides makes it attractive as an absorbent for neutron radiation arising in nuclear power plants[17] and from anti-personnel neutron bombs. Nuclear applications of boron carbide include shielding, name=w330>Weimer, p. 330</ref>

## See also

- List of compounds with carbon number 1

## References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York). ISBN 0-412-54060-6.

## External links

- National Pollutant Inventory – Boron and compounds (https://web.archive.org/web/20060209040519/http://www.npi.gov.au/database/substance-info/profiles/15.html)
- NIST Chemistry Database Entry for Boron Carbide (http://webbook.nist.gov/cgi/cbook.cgi?ID=C12069328&Units=SI&Mask=2#Thermo-Condensed)